(g) Hubble's law; $v \approx H_0 d$ for receding galaxies, where H_0 is the Hubble constant — HSW7

(h) model of an expanding universe supported by galactic red shift — HSW2, 7, 8, 11

(i) Hubble constant H_0 in both $km\,s^{-1}\,Mpc^{-1}$ and s^{-1} units

(d) the Cosmological principle; universe is homogeneous, isotropic and the laws of physics are universal

(6) M - Demonstrate Hubble's law and apply the equation
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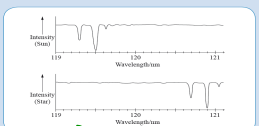
Hubble's law

STARTER: Absorption spectra Q

2 The graphs below show the variation of intensity with wavelength for part of the Sun's spectrum and for the same part of the spectrum from a distant star.



a Explain how the star's motion causes corresponding minima of intensity to occur at different wavelengths. [2]

b Use the graphs to calculate the velocity of the star. [4]

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a The wavelengths have been redshifted. [1]
Hence, the star must be moving away from us. [1]

b $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ [1]

$\frac{v}{c} = \frac{1.4\,nm}{119.5\,nm} = 0.0117$ [1]

$v = 0.0117 \times 3.0 \times 10^8$ [1]

Speed $= 3.5 \times 10^6\,m\,s^{-1}$ [1]

https://imagine.gsfc.nasa.gov/educators/hera_college/binary-model.html

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Hubble's law.

Sketch the graph of Hubble's data.

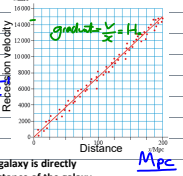
Describe the trend.

v α x

$v = H_0 x$

$H_0 = \frac{v}{x}$

kms

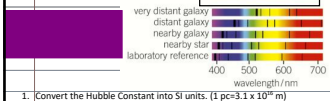


Speed of recession of galaxy is directly proportional to the distance of the galaxy.

What is the unit of the Hubble constant?

What is the unit?

H_0 = Hubble constant = 70 $km\,s^{-1}\,Mpc^{-1}$



1. Convert the Hubble Constant into SI units. (1 pc=3.1 x 10^{16} m)
2. How can H_0 be determined from the graph?

$H_0 = 2.3 \times 10^{-18}\,s^{-1}$

Worked example: Hubble constant units

Convert $1\,km\,s^{-1}\,Mpc^{-1}$ into s^{-1}.

Step 1: Convert the speed into $m\,s^{-1}$ and then divide it by the distance of 1 Mpc in metres.

$1\,km\,s^{-1}\,Mpc^{-1} = \frac{1.0 \times 10^3\,m\,s^{-1}}{10^6 \times 3.1 \times 10^{16}\,m} = 3.2 \times 10^{-20}\,s^{-1}$ (2 s.f.)

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The expanding universe

0:00:00

1. Explain how Hubble law is evidence for the expanding universe.
2. How can Hubble law be used to find an approximate age of the universe? (what assumptions have been made?)

$t \approx \frac{1}{H_0}$

Activity check:

1. Complete Q8,10,14,15,16 on the worksheet.
2. Complete the summary questions

Quick check...

16 A particular galaxy at 80 Mpc is found to have a recession speed of 6000 km s^{-1}.

a Use the information given to calculate a possible value for the Hubble constant in:
i $km\,s^{-1}\,Mpc^{-1}$ [2]
ii s^{-1}. [2]

b Use your answer to part a ii to show that the age of the universe is about 13 000 million years. [3]

c Hence determine the furthest observable distance in metres for the universe. [3]

16 a i $H_0 = \frac{v}{x}$ [1]

$H_0 = \frac{6000}{80} = 75\,km\,s^{-1}\,Mpc^{-1}$ [1]

ii $H_0 = \frac{75 \times 10^3}{10^6 \times 3.1 \times 10^{16}}$ [1]

$H_0 = 2.42 \times 10^{-18}\,s^{-1} \approx 2.4 \times 10^{-18}\,s^{-1}$ [1]

b Age of the universe $= (H_0)^{-1} = \frac{1}{2.42 \times 10^{-18}}$ [1]

age $= 4.13 \times 10^{17}$ s [1]

age $= \frac{4.13 \times 10^{17}}{365 \times 24 \times 3600} = 1.31 \times 10^{10} \approx 13\,000$ million years [1]

c Furthest distance = age of universe × speed of light [1]
furthest distance $= 4.13 \times 10^{17} \times 3.0 \times 10^8$ m [1]
furthest distance $= 1.24 \times 10^{26}$ m $\approx 1.2 \times 10^{26}$ m (4000 Mpc) [1]

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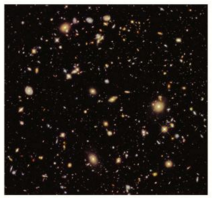

10000 galaxies here, we use the **cosmological principle** to assume there is nothing special about this bit of the universe.

Cosmological Principle

Universe is **isotropic**

Universe is **homogenous**. Density is the same everywhere.

Laws of physics are universal.

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Plenary

MC Question:

Recent data from the European Space Agency's Planck Space Observatory gave a value for the Hubble constant of $2.20 \times 10^{-18}\,s^{-1}$. A previous estimate had been $2.19 \times 10^{-18}\,s^{-1}$.

What is the estimated age of the Universe using the European Space Agency data, and is this within 10% of the age calculated with previous data?

- 14.5 billion years and this is within 10% of the previously calculated value
- 14.4 billion years and this is within 10% of the previously calculated value
- 14.4 billion years and this is not within 10% of the previously calculated value
- 14.5 billion years and this is not within 10% of the previously calculated value

Ex

A star is receding from the Earth with a speed that is 2.5% of the speed of light.

A particular spectral line results from an atomic electron transition between energy levels of energy difference, ΔE.

What is the change in the wavelength, $\Delta\lambda$, of this spectral line in the star's spectrum, in terms of the Planck constant, h, the speed of light, c, and the energy difference, ΔE?

- $\Delta\lambda = 0.025 \times \frac{hc}{\Delta E}$
- $\Delta\lambda = \frac{\Delta E}{(0.025 \times hc)}$
- $\Delta\lambda = \frac{hc}{0.025 \times \Delta E}$
- $\Delta\lambda = \frac{hc}{\Delta E}$

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